

TITLE OF THE INVENTION

OPTICAL AMPLIFIER AND OPTICAL AMPLIFIER  
CONTROL METHOD

5 BACKGROUND OF THE INVENTION

This application claims the benefit of a  
Japanese Patent Application No.2002-333501 filed  
November 18, 2002, in the Japanese Patent Office,  
the disclosure of which is hereby incorporated by  
10 reference. This application is also based on a  
Japanese Patent Application No.2002-173620 filed  
June 14, 2002, in the Japanese Patent Office, the  
disclosure of which is hereby incorporated by  
reference.

15 1. Field of the Invention

The present invention generally relates to  
optical amplifiers and optical amplifier control  
methods, and more particularly to an optical  
amplifier for amplifying optical signals (light  
20 signals or signal lights) and an optical amplifier  
control method for controlling such an optical  
amplifier.

2. Description of the Related Art

Recently, techniques for manufacturing  
25 quartz optical fibers having a low loss on the order  
of 0.2 dB/km, for example, and techniques for  
utilizing such optical fibers, have been established.  
Hence, optical communication systems utilizing such  
optical fibers as transmission lines have been  
30 reduced to practice. In such an optical  
communication system, an optical amplifier is  
provided to amplify the optical signal, so as to  
compensate for the loss of the optical fiber and  
enable a long-distance transmission.

35 A conventional optical amplifier includes  
an optical amplifying medium which receives the  
optical signal to be amplified, and a pumping unit

which pumps (or excites) the optical amplifying medium so as to provide a gain band including a wavelength of the optical signal.

For example, an Erbium (Er) Doped Fiber Amplifier (hereinafter simply referred to as an EDFA) has been developed as one example of an optical amplifier for amplifying an optical signal which has a wavelength of the 1.55  $\mu\text{m}$  band and small loss in the quartz optical fiber.

The EDFA includes an Erbium (Er) Doped Fiber (hereinafter simply referred to as an EDF) as the optical amplifying medium, and a pump light source for supplying pump light having a predetermined wavelength to the EDF. The EDFA uses pump light having a wavelength in the 0.98  $\mu\text{m}$  band or the 1.48  $\mu\text{m}$  band, so as to obtain a gain band including a wavelength of 1.55  $\mu\text{m}$ .

A Wavelength Division Multiplexing (WDM) is a technique for increasing a transmission capacity of the optical fiber. In the optical communication system which is applied with the WDM, a plurality of optical carriers having different wavelengths are used, as proposed in a Japanese Laid-Open Patent Application No.11-122192, for example.

In the optical communication system applied with the WDM, a plurality of optical signals obtained by independently modulating each of the optical carriers are wavelength-division-multiplexed by an optical multiplexer, and a resulting WDM optical signal is supplied to an optical fiber transmission line. At a receiving end, the received WDM optical signal is demultiplexed into individual optical signals by an optical demultiplexer, and transmission data are reproduced based on each of the optical signals. Accordingly, in the optical communication system applied with the WDM, the

transmission capacity of one optical fiber is increased depending on the number of optical signals which are multiplexed.

5 In other words, the optical amplifier is used as a linear repeater in the optical communication system applied with the WDM. For this reason, compared to a case where a conventional reproducing repeater is used, it is possible to reduce the number of parts within the repeater and  
10 secure reliability of the repeater, and also reduce the cost of the repeater.

When assembling the optical amplifier in the optical communication system applied with the WDM, various controls need to be made with respect  
15 to the optical amplifier, due to the necessity to maintain a wavelength characteristic of the gain constant and to prevent waveform deterioration due to non-linear effects of the optical fiber transmission line.

20 For example, in the EDFA, the wavelength characteristic of the gain changes depending on the gain which is determined by the pumping condition, and thus, an Automatic Gain Control (AGC) is carried out so as to produce an output having a  
25 predetermined gain with respect to the input. In this case, if the input changes under the predetermined gain, the output accordingly changes.

On the other hand, from the point of view of a signal-to-noise (S/N) ratio, it is desirable  
30 for the optical amplifier to produce a high signal output. However, if the waveform deterioration due to the non-linear effects of the optical fiber transmission line and an input dynamic range at the receiving end are taken into consideration, it is  
35 not always desirable for the optical amplifier to produce a high signal output. In other words, there are demands to carry out an Automatic Level Control

(ALC), so that the output of the optical amplifier becomes constant within a predetermined range.

As a suitable structure for realizing both the AGC and ALC, an optical amplifier has been  
5 proposed which includes first and second optical amplifier units and a variable optical attenuator connected between the first and second optical amplifier units. According to this proposed optical  
10 amplifier, the AGC is carried out in each of the first and second optical amplifier units, and the ALC is carried out by the variable optical attenuator.

Such an optical amplifier has been proposed for the following reasons. First, from the  
15 point of view of optimizing a Noise Figure (NF) of the entire optical amplifier, it is disadvantageous to provide the variable optical attenuator for the ALC at a preceding stage. Second, from the point of view of securing a predetermined signal output power  
20 of the optical amplifier, if the variable optical attenuator for the ALC is provided at a subsequent stage, it is necessary to obtain a high signal output power in the optical amplifier unit for the AGC at an immediately preceding stage, but this is  
25 disadvantageous from the point of view of realizing a lower power consumption of a laser diode which is used as the pump light source.

In the optical amplifier having the structure which is suited for realizing both the AGC  
30 and the ALC as described above, there is a problem in that the structure of the optical amplifier becomes complex because of the need to independently carry out the AGC in each of the first and second optical amplifier units.

35 In addition, when using the optical amplifier in the optical communication system applied with the WDM, there is a problem in that the

control of the variable optical attenuator for the ALC is complex if a number of channels of the WDM changes. More particularly, when carrying out the ALC to amplify the WDM optical signal in the optical  
5 amplifier, a control is carried out so that the total power of the output of the variable optical attenuator becomes constant. Hence, if the number of channels of the WDM optical signal changes during operation of the optical communication system, a  
10 target value of the control of the variable optical attenuator becomes different.

The target value of the control of the variable optical attenuator is generally supplied from a monitoring control unit which is provided on  
15 an upstream side, and a complex monitoring operation becomes necessary if the wavelength of the optical communication system changes. Moreover, although the attenuation of the variable optical attenuator is temporarily fixed when the wavelength of the  
20 optical amplifier changes, it is necessary to carry out operations such as updating the target value of the control depending on the change in the wavelength in a state where an ALC loop is released and closing the ALC loop again, thereby introducing  
25 a possibility that the attenuation quantity (amount of attenuation) of the variable optical attenuator will vary during the series of operations.

Since the AGC is carried out continuously in the first and second optical amplifier units,  
30 there is a possibility that the output power will vary per wavelength channel when the target value of the control of the variable optical attenuator is switched.

### 35 SUMMARY OF THE INVENTION

Accordingly, it is a general object of the present invention to provide a novel and useful

optical amplifier and an optical amplifier control method, in which the problems described above are eliminated.

Another and more specific object of the present invention is to provide an optical amplifier and an optical amplifier control method, which can prevent a control error when carrying out an AGC and an ALC, using a relatively simple structure, can easily cope with a change in the wavelength, and is applicable to a WDM.

Still another object of the present invention is to provide an optical amplifier comprising first and second optical amplifier units; a variable optical attenuator optically coupled between the first and second optical amplifier units; a first control unit to control gains of the first and second optical amplifier units based on an input of the first optical amplifier unit and an output of the second optical amplifier unit; and a second control unit to control an attenuation quantity of the variable optical attenuator based on the input and an output of the first optical amplifier unit and an input and the output of the second optical amplifier unit. According to the optical amplifier of the present invention, it is possible to prevent a control error when carrying out an AGC and an ALC, using a relatively simple structure, and easily cope with a change in the wavelength, and make it applicable to a WDM. In other words, unlike the conventional case, although the present invention does not carry out the ALC with respect to the variable optical attenuator, the effects of the present invention is as if the ALC were substantially carried out in the optical amplifier as a whole, based on an appropriate combination of the AGC.

A further object of the present invention

is to provide an optical amplifier comprising first and second optical amplifier units; a first variable optical attenuator to attenuate an output of the first optical amplifier unit; a second variable  
5 optical attenuator to attenuate an input of the first optical amplifier unit; a first control unit to control gains of the first and second optical amplifier units based on an output of the second variable optical attenuator and an output of the  
10 second optical amplifier unit; and a second control unit to control attenuation quantities of the first and second variable optical attenuators based on the input and the output of the optical amplifier unit and an input and the output of the second optical  
15 amplifier unit. According to the optical amplifier of the present invention, it is possible to prevent a control error when carrying out an AGC and an ALC, using a relatively simple structure, and easily cope with a change in the wavelength, and make it  
20 applicable to a WDM.

Another object of the present invention is to provide an optical amplifier comprising first and second optical amplifier units; a variable optical attenuator to attenuate an input and an output of  
25 the first optical amplifier unit; a first control unit to control gains of the first and second optical amplifier units based on the input of the first optical amplifier unit which has been attenuated by the variable optical attenuator and an  
30 output of the second optical amplifier unit; and a second control unit to control an attenuation quantity of the variable optical attenuator based on the input of the first optical amplifier unit, the input of the first optical amplifier unit which has  
35 been attenuated by the variable optical attenuator and the output of the second optical amplifier unit. According to the optical amplifier of the present

invention, it is possible to prevent a control error when carrying out an AGC and an ALC, using a relatively simple structure, and easily cope with a change in the wavelength, and make it applicable to a WDM.

Still another object of the present invention is to provide an optical amplifier comprising first and second optical amplifier units; a first variable optical attenuator to attenuate an output of the first optical amplifier unit; a second variable optical attenuator to attenuate an input of the first optical amplifier unit; a first control unit to control gains of the first and second optical amplifier units based on an output of the second variable optical attenuator and an output of the second optical amplifier unit; and a second control unit to control attenuation quantities of the first and second variable optical attenuators based on the output of the second variable optical attenuator, the output of the second optical amplifier unit and characteristics of the first and second variable optical attenuators. According to the optical amplifier of the present invention, it is possible to prevent a control error when carrying out an AGC and an ALC, using a relatively simple structure, and easily cope with a change in the wavelength, and make it applicable to a WDM.

A further object of the present invention is to provide an optical amplifier comprising first and second optical amplifier units; a variable optical attenuator to attenuate an input and an output of the first optical amplifier unit; a first control unit to control gains of the first and second optical amplifier units based on the input of the first optical amplifier unit which has been attenuated by the variable optical attenuator and an output of the second optical amplifier unit; and a



second control unit to control an attenuation quantity of the variable optical attenuator based on the input of the first optical amplifier unit which has been attenuated by the variable optical  
5 attenuator, the output of the second optical amplifier unit, and a characteristic of the variable optical attenuator. According to the optical amplifier of the present invention, it is possible to prevent a control error when carrying out an AGC  
10 and an ALC, using a relatively simple structure, and easily cope with a change in the wavelength, and make it applicable to a WDM.

Another object of the present invention is to provide an optical amplifier control method for  
15 controlling an optical amplifier having first and second optical amplifier units and a variable optical attenuator optically coupled between the first and second optical amplifier units, comprising controlling gains of the first and second optical  
20 amplifier units based on an input of the first optical amplifier unit and an output of the second optical amplifier unit; and controlling an attenuation quantity of the variable optical attenuator based on the input and an output of the  
25 first optical amplifier unit and an input and the output of the second optical amplifier unit. According to the optical amplifier control method of the present invention, it is possible to prevent a control error when carrying out an AGC and an ALC,  
30 using a relatively simple structure, and easily cope with a change in the wavelength, and make it applicable to a WDM.

Still another object of the present invention is to provide an optical amplifier control  
35 method for controlling an optical amplifier having first and second optical amplifier units, a first variable optical attenuator to attenuate an output

of the first optical amplifier unit and a second variable optical attenuator to attenuate an input of the first optical amplifier unit, comprising controlling gains of the first and second optical  
5 amplifier units based on an output of the second variable optical attenuator and an output of the second optical amplifier unit; and controlling attenuation quantities of the first and second variable optical attenuators based on the input and  
10 the output of the optical amplifier unit and an input and the output of the second optical amplifier unit. According to the optical amplifier control method of the present invention, it is possible to prevent a control error when carrying out an AGC and  
15 an ALC, using a relatively simple structure, and easily cope with a change in the wavelength, and make it applicable to a WDM.

A further object of the present invention is to provide an optical amplifier control method for  
20 controlling an optical amplifier having first and second optical amplifier units and a variable optical attenuator to attenuate an input and an output of the first optical amplifier unit, comprising controlling gains of the first and second  
25 optical amplifier units based on the input of the first optical amplifier unit which has been attenuated by the variable optical attenuator and an output of the second optical amplifier unit; and controlling an attenuation quantity of the variable  
30 optical attenuator based on the input of the first optical amplifier unit, the input of the first optical amplifier unit which has been attenuated by the variable optical attenuator and the output of the second optical amplifier unit. According to the  
35 optical amplifier control method of the present invention, it is possible to prevent a control error when carrying out an AGC and an ALC, using a

relatively simple structure, and easily cope with a change in the wavelength, and make it applicable to a WDM.

Another object of the present invention is  
5 to provide an optical amplifier control method for controlling an optical amplifier having first and second optical amplifier units, a first variable optical attenuator to attenuate an output of the first optical amplifier unit and a second variable  
10 optical attenuator to attenuate an input of the first optical amplifier unit, comprising controlling gains of the first and second optical amplifier units based on an output of the second variable optical attenuator and an output of the second  
15 optical amplifier unit; and controlling attenuation quantities of the first and second variable optical attenuators based on the output of the second variable optical attenuator, the output of the second optical amplifier unit and characteristics of  
20 the first and second variable optical attenuators. According to the optical amplifier control method of the present invention, it is possible to prevent a control error when carrying out an AGC and an ALC, using a relatively simple structure, and easily cope  
25 with a change in the wavelength, and make it applicable to a WDM.

Still another object of the present invention is to provide an optical amplifier control method for controlling an optical amplifier having  
30 first and second optical amplifier units and a variable optical attenuator to attenuate an input and an output of the first optical amplifier unit, comprising controlling gains of the first and second optical amplifier units based on the input of the  
35 first optical amplifier unit which has been attenuated by the variable optical attenuator and an output of the second optical amplifier unit; and

controlling an attenuation quantity of the variable optical attenuator based on the input of the first optical amplifier unit which has been attenuated by the variable optical attenuator, the output of the  
5 second optical amplifier unit, and a characteristic of the variable optical attenuator. According to the optical amplifier control method of the present invention, it is possible to prevent a control error when carrying out an AGC and an ALC, using a  
10 relatively simple structure, and easily cope with a change in the wavelength, and make it applicable to a WDM.

Other objects and further features of the present invention will be apparent from the  
15 following detailed description when read in conjunction with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a system block diagram showing a  
20 suitable structure for carrying out both an AGC and an ALC in an optical amplifier;

FIG. 2 is a diagram for explaining an operation of the optical amplifier;

FIG. 3 is a system block diagram showing a  
25 first embodiment of an optical amplifier according to the present invention;

FIG. 4 is a diagram showing a first embodiment of an AGC circuit which controls gains of first and second optical amplifier units;

30 FIG. 5 is a diagram showing a first embodiment of an AGC circuit which controls an attenuation of a variable optical attenuator;

FIG. 6 is a system block diagram showing a second embodiment of the optical amplifier according  
35 to the present invention;

FIG. 7 is a diagram showing a second embodiment of the AGC circuit which controls the

gains of first and second optical amplifier unit;

FIG. 8 is a diagram showing a second embodiment of the AGC circuit which controls the attenuation of a first variable optical attenuator;

5           FIG. 9 is a diagram for explaining an operation of the optical amplifier shown in FIG. 6;

FIG. 10 is a table showing each monitored values of the optical amplifier shown in FIG. 6 and changes in attenuation quantities of the first and  
10           second variable optical attenuators;

FIG. 11 is a system block diagram showing a third embodiment of the optical amplifier according to the present invention;

FIG. 12 is a diagram showing a third  
15           embodiment of the AGC circuit which controls the attenuation of a variable optical attenuator;

FIG. 13 is a diagram for explaining an operation of the optical amplifier shown in FIG. 11;

FIG. 14 is a table showing each monitored  
20           values of the optical amplifier shown in FIG. 11 and changes in an attenuation quantity of the variable optical attenuator;

FIG. 15 is a diagram for explaining a change in an "attenuation quantity of the variable  
25           optical attenuator" versus "driving current (or driving voltage)" relationship due to inconsistencies and temperature characteristics of parts forming the optical amplifier;

FIG. 16 is a system block diagram showing  
30           a fourth embodiment of the optical amplifier according to the present invention;

FIG. 17 is a diagram showing a fourth embodiment of the AGC circuit which controls the attenuations of the first and second variable  
35           optical attenuators;

FIG. 18 is a table showing each monitored values of the optical amplifier shown in FIG. 16 and

changes in the attenuation quantities of the first and second variable optical attenuators;

FIG. 19 is a system block diagram showing a fifth embodiment of the optical amplifier according to the present invention; and

FIG. 20 is a table showing each monitored values of the optical amplifier shown in FIG. 19 and changes in the attenuation quantity of the variable optical attenuator.

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#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

A description will be given of various embodiments of an optical amplifier and an optical amplifier control method according to the present invention, by referring to the drawings.

FIG. 1 is a system block diagram showing a suitable structure for carrying out both an AGC and an ALC in an optical amplifier. An AGC unit 6, an ALC unit 8 and an AGC unit 10 are optical connected in this order between an input end 2 and an output end 4. For example, the AGC units 6 and 10 are formed by an EDFA. In addition, the ALC unit 8 is formed by a variable optical attenuator.

In the AGC unit 6 of the preceding stage, even in a case where a power deviation of an input optical signal is generated, the optical amplification by the AGC is carried out by also taking this power deviation into consideration. In the ALC unit 8, a control is carried out so that an optical power of an output optical signal becomes constant. Hence, even in the case where the power deviation of the input optical signal is generated, the ALC unit 8 carries out the control in a direction so as to suppress the power deviation. Accordingly, in the case of a power deviation having a speed which is sufficiently slower than a control time constant of the ALC unit 8, it is possible to

completely suppress the power deviation of the input optical signal in the ALC unit 8. In addition, in the ALC unit 8, it is possible to indirectly control an optical power of an output signal at the output end 4 to a desired value by setting the following value as a control target value  $P_{ALC}$ , where  $P_{SIGOUT}$  denotes a target power [dB] of the output optical signal at the output end 4, and  $G_B$  denotes a set gain [dB] of the AGC unit 10 of the subsequent stage.

$$P_{ALC} \text{ [dB]} = P_{SIGOUT} - G_B$$

Since the power deviation is suppressed by the ALC unit 8, the optical power of the input optical signal constant in the AGC unit 10 of the subsequent stage. For this reason, the optical power of the output optical signal of the AGC unit 10 becomes constant depending on the operation of the AGC unit 10, and the value of this optical power of the output signal of the AGC unit 10 becomes a target power at the output end 4.

FIG. 2 is a diagram for explaining an operation of the optical amplifier having the structure shown in FIG. 1. In FIG. 2, the ordinate indicates an optical power (W), and the abscissa indicates a time (sec).

In FIG. 2, a graph A indicates a change in the optical power of the optical signal at the input end 2, a graph B indicates a change in the optical power of the optical signal at the input of the ALC unit 8. In addition, a graph C indicates a change in the optical power of the optical signal at the input of the AGC unit 10 of the subsequent stage, and a graph D indicates a change in the optical power of the optical signal at the output end 4.

The change in the optical power of the optical signal at the input end 2 is reflected to

the output of the AGC unit 6 of the preceding stage. The change in the optical power of the optical signal at the input end 2 is suppressed according to the operation of the ALC unit 8. The optical signal,  
5 the optical power of which is suppressed, is amplified by a predetermined gain by the AGC unit 10 of the subsequent stage.

According to the structure of the optical amplifier shown in FIG. 1, the ALC unit 8 is  
10 provided independently, and for this reason, it is difficult to cope with a change in the number of WDM channels, as described above. On the other hand, the present invention makes it possible to easily cope with the change in the number of WDM channels,  
15 by combining AGC units so as to substantially realize ALC functions, as will be described hereunder.

FIG. 3 is a system block diagram showing a first embodiment of an optical amplifier according  
20 to the present invention. The optical amplifier shown in FIG. 3 includes a first optical amplifier unit 16, a Variable Optical Attenuator (VOA) 18 and a second optical amplifier unit 20 which are optically connected between an input end 12 and an  
25 output end 14 in a cascade connection.

An optical signal which is to be amplified and input to the input end 12, is supplied to the first optical amplifier unit 16. In the first optical amplifier unit 16, the optical signal is  
30 supplied to an EDF 26 via an optical coupler 22 and a WDM coupler 24. A pump light from a laser diode 27 is supplied to the EDF 26 via the WDM coupler 24. Hence, it is possible to obtain a gain which is dependent on a power of the pump light. The optical  
35 signal which is amplified in the EDF 26 is output from the first optical amplifier unit 16 via an optical coupler 30.



The optical amplifier shown in FIG. 3 is provided with photodetectors 32 and 34, in order to monitor the an input and an output of the first optical amplifier unit 16. The photodetector 32  
5 converts an optical signal branched by the optical coupler 22 into an electrical signal. The photodetector 34 converts an optical signal branched by the optical coupler 30 into an electrical signal. The electrical signal from the photodetector 32 is  
10 supplied to an AGC circuit 36 which is provided as a first control unit. Further, the electrical signals from the photodetectors 32 and 34 are supplied to an AGC circuit 38 which is provided as a second control unit.

15 The optical signal which is amplified by the first optical amplifier unit 16 is attenuated by the variable optical attenuator 18, and then supplied to the second optical amplifier unit 20. In the second optical amplifier unit 20, the optical  
20 signal is supplied to an EDF 44 via an optical coupler 40 and a WDM coupler 42. Thus, it is possible to obtain a gain which is dependent on the power of the pump light. The optical signal which is amplified in the EDF 44 is output via an optical  
25 coupler 48 and the output end 14.

The optical amplifier shown in FIG. 3 is provided with photodetectors 50 and 52, in order to monitor an input and an output of the second optical amplifier unit 20. The photodetector 50 converts an  
30 optical signal which is branched by the optical coupler 40 into an electrical signal. The photodetector 52 converts an optical signal which is branched by the optical coupler 48 into an electrical signal. The electrical signal from the  
35 photodetector 52 is supplied to the AGC circuit 36. In addition, the electrical signals from the photodetectors 50 and 52 are supplied to the AGC

circuit 38.

A control signal from the AGC circuit 36 is supplied to the laser diodes 28 and 46 which form pump light sources. Hence, a total gain of a total  
5 portion from the input end 12 to the output end 14 is controlled to a target value. Moreover, the AGC circuit 38 controls the attenuation of the variable optical attenuator 18 so that a sum of a gain of the first optical amplifier unit 16 and a gain of the  
10 second optical amplifier unit 20 becomes constant.

Next, a description will be given of a structure of the AGC circuit 36, by referring to FIG. 4. FIG. 4 is a diagram showing a first embodiment of the AGC circuit which controls gains of first and  
15 second optical amplifier units, that is, the AGC circuit 36 which controls the gains of the first and second optical amplifier units 16 and 20. In FIG. 4, the photodetector 32 and a resistor R1 are connected in series between a power supply line Vcc and ground.  
20 A reverse bias is applied to the photodetector 32, and a photocurrent which is dependent on the input of the first optical amplifier unit 16 flows through the photodetector 32 and the resistor R1.

Accordingly, a potential at a node  
25 connecting the photodetector 32 and the resistor R1 may be obtained as a voltage signal dependent on the input to the first optical amplifier unit 16. In order to eliminate a signal component and obtain an average level of the input to the first optical  
30 amplifier unit 16, a capacitor C1 is connected in parallel to the resistor R1.

Similarly, the photodetector 52 and a resistor R2 are connected in series between the power supply line Vcc and the ground. A reverse  
35 bias is applied to the photodetector 52, and a photocurrent which is dependent on the output of the second optical amplifier unit 20 flows through the

photodetector 52 and the resistor R2.

Hence, a potential at a node connecting the photodetector 52 and the resistor R2 may be obtained as a voltage signal dependent on the output  
5 of the second optical amplifier unit 20. In order to eliminate a signal component and obtain an average level of the output of the second optical amplifier unit 20, a capacitor C2 is connected in parallel to the resistor R2.

10 The voltage signal from the photodetector 32 is amplified in a voltage controlled amplifier (VCA) 54 by a gain which is voltage-controlled, and supplied to one input port of a differential  
15 amplifier 66. In addition, the voltage signal from the photodetector 52 is amplified in an amplifier 56 by a gain which is fixed, and supplied to the other input port of the differential amplifier 66.

The outputs of the VCA 54 and the amplifier 56 are converted into digital signals by  
20 corresponding analog-to-digital converters (ADCs) 58 and 60, and supplied to a CPU (or microcontroller) 64. A digital signal which is carried out as a result of an operation within the CPU 64 is converted into a voltage signal by a digital-to-  
25 analog converter (DAC) 62. The gain of the VCA 54 is adjusted based on the voltage signal from the DAC 62.

An amplifier 68, a transistor 70 and a resistor R3 are provided in order to drive the laser  
30 diode 28 which forms the pump light source. In addition, an amplifier 72, a transistor 74 and a resistor R4 are provided in order to drive the laser diode 46 which forms the pump light source. The laser diodes 28 and 46 are driven and controlled  
35 based on an output of the differential amplifier 66.

Resistances of the resistors R1 and R2 and gains of the VCA 54 and the amplifier 56 are set so

as to satisfy the following relationship, where  
V\_AMP1OUT denotes an output level of the amplifier  
56 and V\_VCA1OUT denotes an output level of the VCA  
54. In other words, when the optical power of the  
5 input optical signal of the optical amplifier is  
denoted by  $x$  [dB], the optical power of the output  
optical signal of the optical amplifier is denoted  
by  $x+A$  [dB], and the gain of the optical amplifier  
is denoted by  $A$  [dB], the output levels V\_AMP1OUT  
10 and V\_VCA1OUT of the amplifier 56 and the VCA 54 are  
set to match and become equal to  $y$  [V]. This means  
that the photodetectors 32 and 52 have light  
receiving sensitivities  $[V/W]$  having a ratio  
 $10^{(AMP\_G/10)}$ , where AMP\_G denotes the gain of the  
15 entire optical amplifier.

Since the gain  $A$  [dB] is constant in the  
above described relationship, if the optical power  
of the input optical signal per wavelength channel  
varies, the optical power of the output optical  
20 signal also varies therewith. Hence, an operation  
is carried out in the CPU 64 so that the optical  
power of the output optical signal becomes the  
target value and constant, and the gain of the VCA  
54 is adjusted depending on the operation result.

25 Therefore, this embodiment can  
substantially carry out the ALC by controlling the  
gains of the first and second optical amplifier  
units 16 and 20. Consequently, compared to the  
conventional case where the ALC is carried out by  
30 use of the variable optical attenuator, it becomes  
unnecessary to carry out a troublesome switching  
operation when the number of operating channels is  
changed or the like.

Next, a description will be given of a  
35 structure of the AGC circuit 38, by referring to FIG.  
5. FIG. 5 is a diagram showing a first embodiment  
of the AGC circuit 38 which controls the attenuation

of the variable optical attenuator 18. In FIG. 5, R31, R32, R35, R36 and R37 denote resistors, and C31, C32, C33 and C34 denote capacitors. In order to monitor the input and the output of the first  
5 optical amplifier unit 16, the voltage signals from the photodetectors 32 and 34 are amplified by corresponding amplifiers 354 and 356 having fixed gains, and supplied to corresponding ADCs 362 and 364. The ADCs 362 and 364 convert the voltage  
10 signals from the corresponding photodetectors 332 and 334 into digital signals, and supply the digital signals to a CPU (or microcontroller) 370.

In order to monitor the input and the output of the second optical amplifier unit 20,  
15 voltage signals from the photodetectors 350 and 352 are amplified by corresponding amplifiers 358 and 360 having fixed gains, and supplied to corresponding ADCs 366 and 368. The ADCs 366 and 368 convert the voltage signals from the  
20 corresponding photodetectors 350 and 352 into digital signals, and supply the digital signals to the CPU 370.

The CPU 370 calculates a condition in which a sum of the gain of the first optical  
25 amplifier unit 16 and the gain of the second optical amplifier unit 20 becomes constant. More particularly, the CPU 370 calculates the condition of the attenuation of the variable optical attenuator 18. The calculation result of the CPU  
30 370 is converted into a voltage signal by a DAC 374, and supplied to a driving circuit of the variable optical attenuator 18, including an amplifier 376, a transistor 378 and the resistor R37.

Next, a description will be given of the  
35 control and effects of the variable optical attenuator 18.

When only the control by the AGC circuit

36 shown in FIG. 4 is carried out, it is impossible to maintain the wavelength characteristic of the gain constant in the wavelength band of the WDM optical signal, and there is a possibility that the transmission characteristic will deteriorate due to the generation of a gain tilt. In a structure in which a plurality of optical amplifier units are connected in a cascade connection, the gain of each optical amplifier needs to be controlled constant in order to maintain the wavelength characteristic of the gain constant. But instead, it is possible to control the gains of the plurality of optical amplifier units so that a sum of the gains becomes constant.

If a real gain of the first optical amplifier unit 16 is denoted by  $G\_A'$  [dB], a real gain of the second optical amplifier unit 20 is denoted by  $G\_B'$  [dB], a target gain of the first optical amplifier unit 16 is denoted by  $G\_A$  [dB], and a target gain of the second optical amplifier unit 20 is denoted by  $G\_B$  [dB], a basic control is to make  $G\_A' = G\_A$  and  $G\_B' = G\_B$ .

For example, if the gain of the first optical amplifier unit 16 decreases by  $\Delta G$  [dB], the conventional method controls the gain of the second optical amplifier unit 20 to increase by  $\Delta G$  [dB]. Hence,  $G\_A' + G\_B' = G\_A + G\_B$  is substantially satisfied, and the wavelength characteristic of the gain of the entire optical amplifier is maintained constant.

However, the AGC circuit 36 becomes necessary in each of the first and second optical amplifier units 16 and 20. Further, it is necessary to provide a function of exchanging the gain  $\Delta G$  between the first and second optical amplifier units 16 and 20. As a result, it is difficult to carry out a high-speed AGC.

On the other hand, such problems do not occur in this embodiment, because the variable optical attenuator 18 carries out a control so that the sum of the gains becomes constant. First, the CPU 70 calculates a gain sum EDF\_G' of the gains of the first and second optical amplifier units 16 and 20 according to the following formula, where IN1MON, OUT1MON, IN2MON and OUT2MON respectively denote monitored values of the optical powers of the photodetectors 32, 34, 50 and 52.

$$\begin{aligned}\text{EDF\_G'} &= \text{G\_A'} + \text{G\_B'} \\ &= (\text{OUT1MON} - \text{IN1MON}) + (\text{OUT2MON} - \text{IN2MON})\end{aligned}$$

In addition, the gain sum EDF\_G' and a target value EDF\_G thereof are compared, and the attenuation of the variable optical attenuator 18 is controlled according to the following formula, so that an error between the gain sum EDF\_G' and the target value EDF\_G becomes zero, where AMP\_G denotes the gain of the entire optical amplifier, and VOA\_L denotes the attenuation of the variable optical attenuator 18.

$$\begin{aligned}\text{EDF\_G'} &= (\text{OUT2MON} - \text{IN1MON}) + (\text{OUT1MON} - \text{IN2MON}) \\ &= \text{AMP\_G} + \text{VOA\_L}\end{aligned}$$

Accordingly, by controlling the attenuation of the variable optical attenuator 18 so as to become  $\text{VOA\_L} = \text{EDF\_G'} - \text{AMP\_G}$ , it is possible to easily control the gain of the entire optical amplifier so that the gain is maintained constant.

FIG. 6 is a system block diagram showing a second embodiment of the optical amplifier according to the present invention. The optical amplifier shown in FIG. 6 includes a first optical amplifier unit 86, a first variable optical attenuator (VOA)

88 and a second optical amplifier unit 92 which are optically connected between an input end 82 and an output end 84 in a cascade connection.

5 An optical signal which is to be amplified and input to the input end 82, is supplied to the first optical amplifier unit 86. In the first optical amplifier unit 86, the optical signal is supplied to an EDF 100 via an optical coupler 94 and a WDM coupler 96. A pump light from a laser diode  
10 104 is supplied to the EDF 100 via the WDM coupler 96. Hence, it is possible to obtain a gain which is dependent on a power of the pump light. The optical signal which is amplified in the EDF 100 is output from the first optical amplifier unit 86 via an  
15 optical coupler 102. In addition, an optical signal branched in the optical coupler 94 is output from the first optical amplifier unit 86 via an optical coupler 98.

The optical amplifier shown in FIG. 3 is  
20 provided with photodetectors 106 and 108, in order to monitor the an input and an output of the first optical amplifier unit 86. The photodetector 106 converts the optical signal branched by the optical coupler 98 into an electrical signal. The  
25 photodetector 108 converts an optical signal branched by the optical coupler 102 into an electrical signal. The electrical signals from the photodetectors 106 and 108 are supplied to an AGC circuit 112 which is provided as a second control  
30 unit.

The optical signal which is amplified by the first optical amplifier unit 86 is attenuated by the first variable optical attenuator 88, and then supplied to the second optical amplifier unit 92.  
35 In addition, the optical signal which is branched by the optical coupler 94 is supplied to a second variable optical attenuator (VOA) 90 via the optical



coupler 98, and attenuated. A photodetector 124 is provided in the optical amplifier, in order to monitor the optical signal which is attenuated by the second variable optical attenuator 90.

5           The photodetector 124 converts the optical signal which is attenuated by the second variable optical attenuator 90 into an electrical signal. The electrical signal from the photodetector 124 is supplied to an AGC circuit 110 which is provided as  
10 a first control unit.

          The optical signal supplied to the second optical amplifier unit 92 is supplied to an EDF 118 via an optical coupler 114 and a WDM coupler 116. A pump light from a laser diode 122 is supplied to the  
15 EDF 118 via the WDM coupler 116. Hence, it is possible to obtain a gain which is dependent on the power of the pump light. The optical signal which is amplified by the EDF 118 is output via an optical coupler 120 and the output end 84.

20           The optical amplifier is provided with photodetectors 126 and 128 in order to monitor an input and an output of the second optical amplifier unit 92. The photodetector 126 converts an optical signal which is branched by the optical coupler 114  
25 into an electrical signal. The photodetector 128 converts an optical signal branched by the optical coupler 120 into an electrical signal. The electrical signal from the photodetector 126 is supplied to the AGC circuit 112, and the electrical  
30 signal from the photodetector 128 is supplied to the AGC circuits 110 and 112.

          A control signal from the AGC circuit 110 is supplied to the laser diodes 104 and 122 which form pump light sources. Hence, a total gain of a  
35 total portion from the input end 82 to the output end 84 is controlled to a target value.

          Furthermore, the AGC circuit 112 controls

the attenuation of the first variable optical attenuator 88 so that a sum of the gains of the first and second optical amplifier units 86 and 92 becomes constant. The optical amplifier shown in  
5 FIG. 6 is thus formed by a control circuit section made up of the AGC circuits 110 and 112, and an optical circuit section made up of circuit portions other than the control circuit section.

In the optical amplifier shown in FIG. 6,  
10 a total gain Amp\_Gain of the entire optical amplifier, an EDF gain EDF\_total\_Gain which is a sum of the gains of the first and second optical amplifier units 86 and 92, an attenuation quantity VOA1\_Loss of the first variable optical attenuator  
15 88, and an attenuation quantity VOA2\_Loss of the second variable optical attenuator 90 are controlled, using the electrical signal (hereinafter referred to as a monitored value PD1) from the photodetector 106, the electrical signal (hereinafter referred to as a  
20 monitored value PD2) from the photodetector 108, the electrical signal (hereinafter referred to as a monitored value PD3) from the photodetector 124, the electrical signal (hereinafter referred to as a monitored value PD4) from the photodetector 126 and  
25 the electrical signal (hereinafter referred to as a monitored value PD5) from the photodetector 128.

The monitored value PD1 is obtained by monitoring the input optical signal. The monitored value PD2 is obtained by monitoring the optical  
30 signal which is amplified by the first optical amplifier unit 86. The monitored signal PD3 is obtained by monitoring the optical signal which is attenuated by the second variable optical attenuator 90. The monitored value PD4 is obtained by  
35 monitoring the optical signal which is attenuated by the first variable optical attenuator 88. The monitored value PD5 is obtained by monitoring the

optical signal which is amplified by the second optical amplifier unit 92.

The total gain Amp\_Gain of the entire optical amplifier, the EDF gain EDF\_total\_Gain, the  
5 attenuation quantity VOA1\_Loss of the first variable optical attenuator 88, and the attenuation quantity VOA2\_Loss of the second variable optical attenuator 90 may be obtained from the following formulas using the monitored values PD1 through PD5.

10

$$\begin{aligned}\text{Amp\_Gain} &= \text{PD5} - \text{PD1} \\ \text{VOA1\_Loss} &= \text{PD2} - \text{PD4} \\ \text{VOA2\_Loss} &= \text{PD1} - \text{PD3} \\ \text{EDF\_total\_Gain} &= (\text{PD5} - \text{PD4}) + (\text{PD2} - \text{PD1}) \\ 15 \quad &= (\text{PD5} - \text{PD1}) + (\text{PD2} - \text{PD4}) \\ &= \text{Amp\_Gain} + \text{VOA1\_Loss}\end{aligned}$$

15

Therefore, in the optical amplifier shown in FIG. 6, the attenuation quantity VOA1\_Loss of the  
20 first variable optical attenuator 88 and the total gain Amp\_Gain of the entire optical amplifier are controlled during a normal operation (AGC state).

Next, a description will be given of a structure of the AGC circuit 110, by referring to  
25 FIG. 7. FIG. 7 is a diagram showing a second embodiment of the AGC circuit which controls the gains of the first and second optical amplifier units, that is, the AGC circuit 110 which controls the gains of the first and second optical amplifier  
30 units 86 and 92. The AGC circuit 110 drives the laser diodes 104 and 122 so that the total gain of the entire optical amplifier becomes a desired value, and thus, the total gain of the entire optical amplifier is controlled constant.

35

In the AGC circuit 110 shown in FIG. 7, the photodetector 124 and a resistor R13 are connected in series between the power supply line

Vcc and the ground. A reverse bias is applied to the photodetector 124, and a photocurrent dependent on the output of the second variable optical attenuator 90 flows through the photodetector 124 and the resistor R13.

Accordingly, a potential at a node connecting the photodetector 124 and the resistor R13 may be obtained as a voltage signal dependent on the output of the second variable optical attenuator 90. In order to eliminate a signal component and obtain an average level of the output of the second variable optical attenuator 90, a capacitor C13 is connected in parallel to the resistor R13.

Similarly, the photodetector 128 and a resistor R15 are connected in series between the power supply line Vcc and the ground. A reverse bias is applied to the photodetector 128, and a photocurrent dependent on the output of the second optical amplifier unit 92 flows through the photodetector 128 and the resistor R15.

Hence, a potential at a node connecting the photodetector 128 and the resistor R15 may be obtained as a voltage signal dependent on the output of the second optical amplifier unit 92. In order to eliminate a signal component and obtain an average level of the output of the second optical amplifier unit 92, a capacitor C15 is connected in parallel to the resistor R15.

The voltage signal from the photodetector 124 is subjected to an impedance conversion and amplification in an amplifier 130 having a fixed gain, and supplied to one input port of a differential amplifier 134. The voltage signal from the photodetector 128 is subjected to an impedance conversion and amplification in an amplifier 132 having a fixed gain, and supplied to the other input port of the differential amplifier 134.

The optical amplifier is provided with an amplifier 136, a transistor 138 and a resistor R11 in order to drive the laser diode 104 which forms the pump light source. In addition, the optical  
5 amplifier is provided with an amplifier 140, a transistor 142 and a resistor R12 in order to drive the laser diode 122 which forms a pump light source. These laser diodes 104 and 122 are driven and controlled based on an output of the differential  
10 amplifier 134.

If output levels of the amplifiers 130 and 132 are respectively denoted by Amp3\_OUT and Amp5\_OUT, the resistances of the resistors R13 and R15 and the gains of the amplifiers 130 and 132 are  
15 set to satisfy the following relationship. In other words, when the monitored value PD3 is denoted by  $x$  [dBm], and the monitored value PD5 is denoted by  $x + \text{Amp\_Gain}$  reference value [dBm], where Amp\_Gain reference value denotes a reference value of the  
20 gain Amp\_Gain of the entire optical amplifier, the output levels Amp3\_OUT and Amp5\_OUT of the amplifiers 130 and 132 are set to match and become equal to  $y$  [V], by setting monitoring circuits related to the photodetectors 124 and 128 to have  
25 light receiving sensitivities [V/W]. This means that the light receiving sensitivities [V/W] of the monitoring circuits related to the photodetectors 124 and 128 have a ratio  $10^{(\text{AMP\_G}/10)}$ , where AMP\_G denotes the gain of the entire optical amplifier.

30 The output of the differential amplifier 134 drives and controls the laser diodes 104 and 122 so that an error between the voltage signals supplied to the input ports of the differential amplifier 134 becomes zero. Therefore, in the  
35 optical amplifier shown in FIG. 6, it is possible to maintain the gain of the entire optical amplifier constant even when the wavelength changes.

However, since the Amp\_Gain reference value of the entire optical amplifier is constant according to the above described relationship, if the optical power of the input optical signal varies  
5 per wavelength channel, the optical power of the output optical signal varies therewith. Hence, in the optical amplifier shown in FIG. 6, the ALC described later is used to compensate for and control the deviation of the input optical signal,  
10 so that the optical power of the output optical signal becomes a control target value which is constant.

In the optical amplifier, it is necessary to absorb an input dynamic range caused by  
15 inconsistencies in the transmission line loss, deterioration due to aging of the optical fiber transmission line and the like. This input dynamic range absorption is realized by the ALC. In the ALC state, information indicating the wavelength is  
20 notified from a monitoring control unit which is provided on an upstream side with respect to the optical amplifier, and this information is used to determine the output target value of the optical amplifier.

25 In the conventional optical amplifier, the variable optical attenuator is driven so that the signal output of the ALC unit 8 shown in FIG. 1 in the intermediate stage becomes the control target value, by controlling the attenuation quantity of  
30 the variable optical attenuator. This control target value may be calculated as follows, where  $G_c$  denotes an insufficient gain of the AGC unit 6 in the preceding stage.

35 (Control Target Value of ALC Unit) [dBm] =  
(Output Reference Value of ALC Unit) [dBm/ch] +  
 $10\log(\text{Wavelength}) - G_c$  [dB]

The insufficient gain  $G_c$  may be calculated as follows.

$$\begin{aligned} 5 \quad G_c [\text{dB}] &= (\text{Gain Target Value of AGC Unit}) [\text{dB}] \\ &- (\text{Gain of AGC}) [\text{dB}] \end{aligned}$$

Therefore, the gain target value of the AGC unit 10 in the subsequent stage shown in FIG. 1 needs to be increased by  $G_c$  [dB]. From the point of view of obtaining desired NF and pumping (excitation) efficiency for the entire optical amplifier, the variable optical attenuator is located in the intermediate stage of the optical amplifier.

On the other hand, in this embodiment of the optical amplifier, the deviation of the input optical signal is not compensated by controlling the attenuation quantity of the first variable optical attenuator 88. As described above, the present invention controls the output optical signal to change by an amount of deviation of the input optical signal, by controlling the gain of the entire optical amplifier constant. Moreover, this embodiment maintains the attenuation quantity of the first variable optical attenuator 88 constant by the control of the AGC circuit 112, as described later.

In the case of an optical amplifier which controls the gains of the first and second optical amplifier units 86 and 92 by a single AGC circuit 110, if the input optical signal per wavelength channel deviates, the output optical signal varies therewith. For this reason, it is necessary to provide a circuit, a microcontroller or the like for compensating for the deviation of the input optical signal per wavelength channel. As a result, noise and response speed of the circuit, microcontroller

or the like for compensating for the deviation of the input optical signal may adversely affect the control circuit section to deteriorate the characteristics of the optical amplifier.

5 But in this embodiment of the optical amplifier, the optical circuit section compensates for the deviation of the input optical signal, and it is unnecessary to compensate using the control circuit section, as described hereunder with  
10 reference to Processing Methods P1 and P2.

[Processing Method P1]

According to the processing method P1, a position information of the input optical signal within the input dynamic range is recognized based  
15 on the monitored value PD1. The attenuation quantity of the second variable optical attenuator 90 is controlled based on the recognized position information, so that the output signal level is controlled constant. The optical amplifier  
20 calculates the following values which are necessary for the control, using the information related to the wavelength notified from the monitoring control unit which is provided on the upstream side of the optical amplifier, where  $L_d$  denotes the attenuation  
25 quantity (dead loss) of the second variable optical attenuator 90 when the optical power of the input optical signal per wavelength channel is  $u$  [dBm/ch].

Monitored Value PD1:  $z_1$  [dBm]  
30 Monitored Value PD3:  $z_3$  [dBm]  
Information of Wavelength of Input Signal:  $N$   
Optical Power of Input Optical Signal:  
 $z_1 - 10\log(N)$  [dBm/ch]  
Upper Limit Value of Optical Power of Input  
35 Optical Signal Per Wavelength Channel:  $u$  [dBm/ch]  
Position Information Within Input Dynamic  
Range:  $L_0 = u - \{z_1 - 10\log(N)\}$



Attenuation Quantity of Second Variable Optical  
Attenuator 90:  $L = z1 - z3 - Ld$  [dB]

The values  $z1 - 10\log(N)$  [dBm/ch],  $L0 = u$   
5  $- \{z1 - 10\log(N)\}$ , and  $L = z1 - z3 - Ld$  [dB] may be  
calculated by a microcontroller or the like. In  
addition, the value  $u$  [dBm/ch] may be stored in a  
ROM, for example.

In this embodiment of the optical  
10 amplifier, the attenuation quantity  $L$  of the second  
variable optical attenuator 90 is controlled is  
controlled to becomes  $L = L0$ , by calculating the  
deviation (corresponding to  $L0$ ) of the input optical  
signal per wavelength channel. By this process, the  
15 output value of the amplifier 130 will not change  
even when the optical power of the input optical  
signal per wavelength channel changes.

As a result, the optical power of the  
output optical signal from the optical amplifier is  
20 controlled constant and the ALC operation is  
realized, because the output value of the amplifier  
132 is also controlled by the AGC circuit 110 so as  
not to change.

[Processing Method P2]

25 According to the processing method P2, the  
monitored value PD5 and the output signal reference  
value are compared, and the attenuation quantity of  
the second variable optical attenuator 90 is  
controlled so that an error between the compared  
30 values becomes zero. The optical amplifier  
calculates the following values which are necessary  
for the control, using the information related to  
the wavelength notified from the monitoring control  
unit which is provided on the upstream side of the  
35 optical amplifier.

Monitored Value PD5:  $z5$  [dBm]

Information of Wavelength of Input Signal: N

Output Reference Value Per Wavelength Channel:

A0 [dBm/ch]

Optical Power of Output Optical Signal:

5     $A = z5 - 10\log(N)$  [dBm/ch]

10        The value A may be calculated by a microcontroller or the like, for example. The value A0 may be stored in a ROM, for example. In this embodiment of the optical amplifier, it is possible to control the optical power A of the output optical signal per wavelength channel by the attenuation quantity L of the second variable optical attenuator 90. Hence, the ALC operation can be realized by  
15    controlling the attenuation quantity L of the second variable optical attenuator 90 so that the optical power A of the output optical signal becomes  $A = A0$ . In this processing method P2, the attenuation quantity L of the second variable optical attenuator  
20    90 is  $L = L0$  as in the case of the processing method P1.

By controlling the gain of the entire optical amplifier constant and carrying out the ALC operation only, the signal gain characteristic  
25    cannot be maintained constant in the optical signal wavelength region due to the effects of the EDF gain tilt. For this reason, in this embodiment of the optical amplifier, the EDF gain is controlled constant in order to maintain the gain tilt  
30    characteristic constant.

Next, a description will be given of a structure of the AGC circuit 112, by referring to FIG. 8. FIG. 8 is a diagram showing a second embodiment of the AGC circuit 112 which controls the  
35    attenuation of the first variable optical attenuator 88. In FIG. 8, R21, R22, R24, R25 and R26 denote resistors, and C21, C22, C24 and C25 denote

capacitors. In order to monitor the input and the output of the first optical amplifier unit 86, the voltage signals from the photodetectors 106 and 108 are amplified by corresponding amplifiers 150 and 5 152 having fixed gains, and supplied to corresponding ADCs 158 and 160. The ADCs 158 and 160 convert the voltage signals from the corresponding photodetectors 106 and 108 into digital signals, and supply the digital signals to a 10 microcontroller (or CPU) 166.

In order to monitor the input and the output of the second optical amplifier unit 92, voltage signals from the photodetectors 126 and 128 are amplified by corresponding amplifiers 154 and 15 156 having fixed gains, and supplied to corresponding ADCs 162 and 164. The ADCs 162 and 164 convert the voltage signals from the corresponding photodetectors 126 and 128 into digital signals, and supply the digital signals to 20 the microcontroller 166.

The microcontroller 166 calculates the EDF gain by adding the gain of the entire optical amplifier and the attenuation quantity of the first variable optical attenuator 88. Hence, by driving 25 the first variable optical attenuator 88 so that the attenuation quantity thereof becomes a target value (VOA1\_Loss target value) described by the following, the microcontroller 166 can control the EDF gain constant.

30

$$(\text{VOA1\_Loss Target Value}) = (\text{Gain of Entire Optical Amplifier}) - (\text{EDF Gain Target Value})$$

The microcontroller 166 calculates the 35 target value of the attenuation quantity of the first variable optical attenuator 88, and controls the first variable optical attenuator 88 so that the

attenuation quantity thereof becomes the target value. A control signal which is output from the microcontroller 166 so as to control the first variable optical attenuator 88 is converted into a voltage signal by a DAC 168, and is supplied to a driving circuit for the first variable optical attenuator 88. This driving circuit includes an amplifier 170, a transistor 172 and the resistor R26.

Next, a description will be given of the operation of the optical amplifier shown in FIG. 6, by referring to FIGS. 9 and 10. FIG. 9 is a diagram for explaining the operation of the optical amplifier, and FIG. 10 is a table showing each monitored values of the optical amplifier and changes in attenuation quantities of the first and second variable optical attenuators 88 and 90.

In FIG. 9, a graph 180 shows an initial setting control state where initial values are set so that the monitored values PD1 and PD3 have the same value when the input has the upper limit (or a level other than the upper limit). The attenuation quantity of the first variable optical attenuator 88 is set to the initial value stored in the ROM, for example.

A graph 182 shows an input change control state where a change is introduced in the input signal. The graph 182 changes so that the signal power is smaller than that of the graph 180.

A graph 184 shows a change correcting control state where the amount of change of the input signal is calculated and the attenuation quantity of the second variable optical attenuator 90 is controlled so as to correct the amount of change. The amount of change of the input signal per wavelength channel is corrected by controlling the attenuation quantity of the second variable optical attenuator 90. In addition, a graph 186

shows a state where gain of the entire optical amplifier is controlled constant by the AGC using the monitored values PD3 and PD5, and the attenuation quantity of the first variable optical attenuator 88 is controlled so as to maintain the EDF gain target value.

In FIG. 10, "X" indicates an input signal power, and " $\alpha$ " indicates an amount of change. Further, "L1" indicates the attenuation quantity of the first variable optical attenuator 88, "L2" indicates the attenuation quantity of the second variable optical attenuator 90, and "A" indicates the gain of the entire optical amplifier.

In this embodiment, the first and second variable optical attenuators 88 and 90 are controlled independently. However, when the input signal level changes by X [dB] per wavelength channel, the attenuation quantities of the first and second variable optical attenuators 88 and 90 respectively become X [dB]. Hence, a description will now be given of a case where processes similar to those carried out by the second embodiment of the optical amplifier having the first and second variable optical attenuators 88 and 90 are carried out in an optical amplifier having a single variable optical attenuator.

FIG. 11 is a system block diagram showing a third embodiment of the optical amplifier according to the present invention. The optical amplifier shown in FIG. 11 includes a first optical amplifier unit 196, a variable optical attenuator (VOA) 198 and a second optical amplifier unit 200 which are optically connected in a cascade connection between an input end 192 and an output end 194.

An optical signal which is to be amplified and input to the input end 192, is supplied to the

first optical amplifier unit 196. In the first optical amplifier unit 196, the optical signal is supplied to an EDF 206 via an optical coupler 202 and a WDM coupler 204. A pump light from a laser diode 212 is supplied to the EDF 206 via the WDM coupler 204. Hence, it is possible to obtain a gain which is dependent on a power of the pump light. The optical signal which is amplified in the EDF 206 is output from the first optical amplifier unit 196 via an isolator 208 and an optical coupler 210. In addition, a first branch optical signal branched in the optical coupler 202 is output as it is from the first optical amplifier unit 196.

The optical signal amplified by the first optical amplifier unit 196 is attenuated in the variable optical attenuator 198 and then supplied to the second optical amplifier unit 200. In the second optical amplifier unit 200, the optical signal is supplied to an EDF 226 via an optical coupler 220, an isolator 222 and a WDM coupler 224. A pump light from a laser diode 232 is supplied to the EDF 226 via the WDM coupler 224. Thus, it is possible to obtain a gain which is dependent on the power of the pump light. The optical signal amplified in the EDF 226 is output via an optical coupler 228 and the output end 194.

The first branch optical signal output from the first optical amplifier unit 196 is supplied to the optical coupler 220 of the second optical amplifier unit 200, and branched into second and third branch optical signals. The third branch optical signal is attenuated in the variable optical attenuator 198 and then supplied to the optical coupler 210. The third branch optical signal supplied to the optical coupler 210 is branched into a fourth branch optical signal.

The optical amplifier shown in FIG. 11 is

provided with a photodetector 230, in order to monitor the an input and an output of the first optical amplifier unit 196. The photodetector 230 converts the second branch optical signal branched  
5 by the optical coupler 220 into an electrical signal.

The optical amplifier is also provided with a photodetector 214, in order to monitor the optical signal which reflects the attenuation in the variable optical attenuator 198 to the input of the  
10 first optical amplifier unit 196. The photodetector 214 converts the fourth branch optical signal branched by the optical coupler 210 into an electrical signal.

The optical amplifier is further provided  
15 with a photodetector 234, in order to monitor the output of the second optical amplifier unit 200. The photodetector 234 converts the fifth branch optical signal branched by the optical coupler 228 into an electrical signal.

20 The electrical signal from the photodetector 230 is supplied to an AGC circuit 218 which forms a second control unit. In addition, the electrical signals from the photodetectors 214 and 234 are supplied to the AGC circuit 218 and an AGC  
25 circuit 216 which forms a first control unit.

A control signal from the AGC circuit 216 is supplied to the laser diodes 212 and 232 which form pump light sources. Hence, a total gain of a total section from the input end 192 to the output  
30 end 194 is controlled to a target value.

Furthermore, the AGC circuit 218 controls the attenuation of the variable optical attenuator 198 so that a sum of the gains of the first and second optical amplifier units 196 and 200 becomes  
35 constant. The optical amplifier shown in FIG. 11 is thus formed by a control circuit section made up of the AGC circuits 216 and 218, and an optical circuit

section made up of circuit portions other than the control circuit section.

In the optical amplifier shown in FIG. 11, the gain of the entire optical amplifier, the EDF gain and the attenuation quantity of the variable optical attenuator 198 are controlled, using the electrical signal (monitored value PD1) from the photodetector 214, the electrical signal (monitored value PD2) from the photodetector 230, and the electrical signal (monitored value PD3) from the photodetector 234.

The isolator 208 prevents the fourth branch optical signal from entering the EDF 206. The isolator 222 prevents an output Back\_ASE of the EDF 226 from entering the photodetectors 214 and 230.

The gain Amp\_Gain of the entire optical amplifier, the EDF gain EDF\_total\_Gain, and the attenuation quantity VOA\_Loss of the variable optical attenuator 198 may be obtained from the monitored values PD1 through PD3 as follows.

$$\begin{aligned}\text{Amp\_Gain} &= \text{PD3} - \text{PD2} \\ \text{VOA\_Loss} &= \text{PD2} - \text{PD1} \\ \text{EDF\_total\_Gain} &= \text{Amp\_Gain} + \text{VOA\_Loss} \\ &= (\text{PD3} - \text{PD2}) + (\text{PD2} - \text{PD1}) \\ &= (\text{PD3} - \text{PD1})\end{aligned}$$

Accordingly, as may be seen from the above relationship, the gain Amp\_Gain of the entire optical amplifier and the attenuation quantity VOA\_Loss of the variable optical attenuator 198 are controlled during the normal operation (AGC state) of the optical amplifier shown in FIG. 11.

Next, a description will be given of a process carried out by the AGC circuit 216. Since the AGC circuit 216 drives the laser diodes 212 and 232 so that the gain of the entire optical amplifier becomes a desired value, the gain of the entire



optical amplifier is controlled constant. The structure of the AGC circuit 216 may be the same as the structure of the AGC circuit 110 described above.

The gain of the entire optical amplifier  
5 may be controlled constant, similarly to the second embodiment described above, by controlling the outputs of the laser diodes 212 and 232 so that the gain of the entire optical amplifier calculated from the monitored values PD1 and PD2 becomes the desired  
10 value. In actual practice, the gain of the entire optical amplifier is controlled constant based on the monitored values PD1 and PD3 so that the following set conditions are satisfied.

In other words, when the monitored values  
15 PD1 and PD3 are respectively denoted by  $x$  [dBm] and  $x + \text{Amp\_Gain}$  reference value [dBm], monitoring circuits related to the photodetectors 214 and 234 are set to have light receiving sensitivities [V/W], so that the output levels of the amplifiers 130 and  
20 132 match and become equal to  $y$  [V].

An output of a differential amplifier of the AGC circuit 216, corresponding to the differential amplifier 134 of the AGC circuit 110 shown in FIG. 7, drives and controls the laser  
25 diodes 212 and 232 so that an error between the voltage signals supplied to the input ports of the differential amplifier becomes zero. Therefore, in the optical amplifier shown in FIG. 11, it is possible to maintain the gain of the entire optical  
30 amplifier constant even when the wavelength changes.

In the optical amplifier shown in FIG. 11, it is also necessary to cope with the deviation of the optical power of the input optical signal per wavelength channel, and the deviation of the optical  
35 power of the input optical signal is compensated by using the ALC. In the ALC state, information indicating the wavelength is notified from a

monitoring control unit which is provided on an upstream side with respect to the optical amplifier, and this information may be used to determine the output target value of the optical amplifier,  
5 similarly to the second embodiment of the optical amplifier described above.

[Processing Method P3]

According to the processing method P3, a position information of the input optical signal  
10 within the input dynamic range is recognized based on the monitored value PD2. The attenuation quantity of the variable optical attenuator 198 is controlled based on the recognized position information, so that the output signal level is  
15 controlled constant. The optical amplifier calculates the following values which are necessary for the control, using the information related to the wavelength notified from the monitoring control unit which is provided on the upstream side of the  
20 optical amplifier, where  $L_d$  denotes the attenuation quantity (dead loss) of the variable optical attenuator 198 when the optical power of the input optical signal per wavelength channel is  $u$  [dBm/ch].

25        Monitored Value PD1:  $z_1$  [dBm]  
         Monitored Value PD2:  $z_2$  [dBm]  
         Information of Wavelength of Input Signal:  $N$   
         Optical Power of Input Optical Signal:  
          $z_2 - 10\log(N)$  [dBm/ch]  
30        Upper Limit Value of Optical Power of Input  
         Optical Signal Per Wavelength Channel:  $u$  [dBm/ch]  
         Position Information Within Input Dynamic  
         Range:  $L_0 = u - \{z_2 - 10\log(N)\}$   
         Attenuation Quantity of Second Variable Optical  
35 Attenuator 90:  $L = z_2 - z_1 - L_d$  [dB]

The values  $z_2 - 10\log(N)$  [dBm/ch],  $L_0 = u$

-  $\{z_2 - 10\log(N)\}$ , and  $L = z_2 - z_1 - L_d$  [dB] may be calculated by a microcontroller or the like. In addition, the value  $u$  [dBm/ch] may be stored in a ROM, for example.

5                   In this embodiment of the optical amplifier, the attenuation quantity  $L$  of the variable optical attenuator 198 is controlled is controlled to becomes  $L = L_0$ , by calculating the deviation (corresponding to  $L_0$ ) of the input optical  
10 signal per wavelength channel. By this process, the optical power of the output optical signal of the optical amplifier becomes the target value  $\{PD_1 + (\text{gain target value of entire optical amplifier})\}$  by carrying out the AGC operation using the monitored  
15 values  $PD_1$  and  $PD_3$ , even when the optical power of the input optical signal per wavelength channel changes.

[Processing Method P4]

                  According to the processing method P4, the  
20 monitored value  $PD_3$  and the output signal reference value are compared, and the attenuation quantity of the variable optical attenuator 198 is controlled so that an error between the compared values becomes zero. The optical amplifier calculates the  
25 following values which are necessary for the control, using the information related to the wavelength notified from the monitoring control unit which is provided on the upstream side of the optical amplifier.

30

Monitored Value  $PD_3$ :  $z_3$  [dBm]

Information of Wavelength of Input Signal:  $N$

Output Reference Value Per Wavelength Channel:

$A_0$  [dBm/ch]

35

Optical Power of Output Optical Signal:

$A = z_3 - 10\log(N)$  [dBm/ch]

The value A may be calculated by a microcontroller or the like, for example. The value A0 may be stored in a ROM, for example. In this embodiment of the optical amplifier, it is possible to control the optical power A of the output optical signal per wavelength channel by the attenuation quantity L of the variable optical attenuator 198. Hence, the ALC operation can be realized by controlling the attenuation quantity L of the variable optical attenuator 198 so that the optical power A of the output optical signal becomes  $A = A_0$ . In this processing method P4, the attenuation quantity L of the variable optical attenuator 198 is  $L = L_0$  as in the case of the processing method P3.

The ALC operation may be carried out by controlling the attenuation quantity of the variable optical attenuator 198 so as to satisfy the target value of the processing method P3 or P4. Since the changing speed of the attenuation quantity of the variable optical attenuator 198 and the correcting speed of the monitored value PD1 become the same during the ALC operation, the EDF gain always takes a constant value even during the ALC operation. In other words, the gain tilt will not be generated during the ALC operation.

As described above with respect to the EDF gain of the second embodiment which is controlled constant, the EDF gain is controlled constant in this embodiment by controlling the attenuation quantity of the variable optical attenuator 198 to the target value.

Next, a description will be given of a structure of the AGC circuit 218, by referring to FIG. 12. FIG. 12 is a diagram showing a third embodiment of the AGC circuit 218 which controls the attenuation of the variable optical attenuator 198. In FIG. 12, R41, R42, R43 and R45 denote resistors,

and C41, C42 and C43 denote capacitors. The monitored values PD1, PD2 and PD3 are amplified by corresponding amplifiers 140, 142 and 244 having fixed gains, and the supplied to corresponding ADCs  
5 246, 248 and 250. The ADCs 246, 248 and 250 convert the respective monitored values PD1, PD2 and PD3 into digital signals, and supply the digital signals to a microcontroller (or CPU) 252.

The microcontroller 252 calculates the EDF  
10 gain by adding the gain of the entire optical amplifier and the attenuation quantity of the variable optical attenuator 198. Hence, by driving the variable optical attenuator 198 so that the attenuation quantity thereof becomes a target value  
15 (VOA1\_Loss target value) described by the following, the microcontroller 252 can control the EDF gain constant.

(VOA1\_Loss Target Value) = (Gain of Entire  
20 Optical Amplifier) - (EDF Gain Target Value)

The microcontroller 252 calculates the target value of the attenuation quantity of the variable optical attenuator 198, and controls the  
25 variable optical attenuator 198 so that the attenuation quantity thereof becomes the target value. A control signal which is output from the microcontroller 252 so as to control the variable optical attenuator 198 is converted into a voltage  
30 signal by a DAC 254, and is supplied to a driving circuit for the variable optical attenuator 198. This driving circuit includes an amplifier 256, a transistor 258 and the resistor R45. In this third embodiment, it is only necessary to control the  
35 attenuation quantity of the variable optical attenuator 198 constant, because the EDF gain becomes the target value simultaneously as when the

ALC operation is carried out.

Next, a description will be given of the operation of the optical amplifier shown in FIG. 11, by referring to FIGS. 13 and 14. FIG. 13 is a  
5 diagram for explaining the operation of the optical amplifier, and FIG. 14 is a table showing each monitored values of the optical amplifier and changes in the attenuation quantity of the variable optical attenuator 198.

10 In FIG. 13, a graph 260 shows an initial setting control state where initial values are set so that the monitored values PD1 and PD2 have the same value when the input has the upper limit (or a level other than the upper limit). The attenuation  
15 quantity of the variable optical attenuator 198 is set to a value obtained by subtracting the EDF gain target value from the reference value of the gain of the entire optical amplifier.

A graph 262 shows an input change control  
20 state where a change is introduced in the input signal. The graph 262 changes so that the signal power is smaller than that of the graph 260.

A graph 264 shows a change correcting control state and a control state where the gain of  
25 the entire optical amplifier is controlled constant. The optical amplifier calculates the amount of change of the input signal, and controls the attenuation quantity of the variable optical attenuator 198 so as to correct the amount of change.  
30 When the attenuation quantity of the variable optical attenuator 198 is controlled by the ALC operation, the EDF gain becomes the target value. The amount of change of the input signal per wavelength channel is corrected by controlling the  
35 attenuation quantity of the variable optical attenuator 198. In addition, the gain of the entire optical amplifier is controlled constant by the AGC

using the monitored values PD1 and PD3.

In FIG. 14, "X" indicates an input signal power, and " $\alpha$ " indicates an amount of change.

Further, "L" indicates the attenuation quantity of  
5 the variable optical attenuator 198, and "A"  
indicates the gain of the entire optical amplifier.

In the second and third embodiments of the optical amplifier described above, the "attenuation quantity of the variable optical attenuator" versus  
10 "driving current (or driving voltage)" relationship changes due to inconsistencies and temperature characteristics of the parts forming the optical amplifier. Hence, the variable optical attenuator is controlled while monitoring the attenuation  
15 quantity from the monitored values, as shown in FIG. 15. FIG. 15 is a diagram for explaining the change in the "attenuation quantity of the variable optical attenuator" versus "driving current (or driving voltage)" relationship due to the inconsistencies  
20 and temperature characteristics of the parts forming the optical amplifier. In FIG. 15, the ordinate indicates the attenuation quantity [dB] of the variable optical attenuator, and the abscissa indicates the driving current [A].

25 However, if the optical amplifier is constructed to have the characteristics of the variable optical attenuator within the optical amplifier, it is possible to control the attenuation quantity of the variable optical attenuator by  
30 controlling the driving current of the variable optical attenuator. Hence, if the "attenuation quantity of the variable optical attenuator" versus "driving current (or driving voltage)" relationship is known in the second or third embodiment, the  
35 number of optical circuit parts may be reduced by constructing the optical amplifier as shown in FIGS. 16 through 19.

FIG. 16 is a system block diagram showing a fourth embodiment of the optical amplifier according to the present invention. In FIG. 16, those parts which are the same as those corresponding parts in FIG. 6 are designated by the same reference numerals, and a description thereof will be omitted. The optical amplifier shown in FIG. 16 differs from the optical amplifier shown in FIG. 6 in that the photodetectors 106, 108 and 126 shown in FIG. 6 are omitted. The optical amplifier shown in FIG. 16 stores the characteristics of the variable optical attenuators in the form of a table or function, and drives the variable optical attenuators based on a value which is processed by a microcontroller or the like.

The gain Amp\_Gain of the entire optical amplifier, the EDF gain EDF\_total\_Gain, the attenuation quantity VOA1\_Loss of the first variable optical attenuator 88, and the attenuation quantity VOA2\_Loss of the second variable optical attenuator 90 may be obtained as follows using the monitored values PD3 and PD5. A sum of the monitored value PD3 and the attenuation quantity of the second variable optical attenuator 90 corresponds to the optical power of the input optical signal.

$$\begin{aligned}\text{Amp\_Gain} &= \text{PD5} - (\text{PD3} + \text{VOA2\_Loss}) \\ \text{EDF\_total\_Gain} &= \text{Amp\_Gain} + \text{VOA1\_Loss}\end{aligned}$$

The gain of the entire optical amplifier is controlled by driving the laser diodes 104 and 122 so that the gain of the entire optical amplifier calculated from the monitored values PD3 and PD5 becomes the desired value. Since the structure of the AGC circuit 110 is the same as that shown in FIG. 7, illustration and description thereof will be omitted.



Similarly to the second embodiment described above, the ALC operation calculates the change in the input optical signal per wavelength channel from the monitored value of the input  
5 optical signal and the output optical signal, and drives the first and second variable optical attenuators 88 and 90 using the calculated value as the target value.

Furthermore, the optical amplifier shown  
10 in FIG. 16 controls the EDF gain constant by using the AGC circuit 112 having a structure shown in FIG. 17. FIG. 17 is a diagram showing a fourth embodiment of the AGC circuit 112 which controls the attenuations of the first and second variable  
15 optical attenuators 88 and 90. In FIG. 17, R53, R55 and R56 denote resistors, and C53 and C55 denote capacitors.

The voltage signals from the photodetectors 124 and 128 are amplified in  
20 corresponding amplifiers 270 and 272 having fixed gains, and supplied to corresponding ADCs 274 and 276. The ADCs 274 and 276 convert the voltage signals from the respective photodetectors 124 and 128 into digital signals, and supply the digital  
25 signals to a microcontroller 278.

Similarly to the second embodiment described above, the microcontroller 278 can calculate the EDF gain by adding the gain of the entire optical amplifier and the attenuation  
30 quantity of the first variable optical attenuator 88. For this reason, by driving the first variable optical attenuator 88 so that the attenuation quantity of the first variable optical attenuator 88 becomes the target value VOA1\_Loss, the  
35 microcontroller 278 can control the EDF gain constant.

(VOA1\_Loss Target Value) = (Gain of Entire  
Optical Amplifier) - (EDF Gain Target Value)

The microcontroller 278 calculates the  
5 target value of the attenuation quantity of the  
first variable optical attenuator 88, and controls  
the first variable optical attenuator 88 so that the  
attenuation quantity thereof becomes the target  
value. A control signal which is output from the  
10 microcontroller 278 so as to control the first  
variable optical attenuator 88 is converted into a  
voltage signal by a DAC 280, and is supplied to a  
driving circuit for the first variable optical  
attenuator 88. This driving circuit includes an  
15 amplifier 282, a transistor 284 and the resistor R56.

Next, a description will be given of the  
operation of the optical amplifier shown in FIG. 16,  
by referring to FIG. 18. FIG. 18 is a table showing  
each monitored values of the optical amplifier and  
20 changes in attenuation quantities of the first and  
second variable optical attenuators 88 and 90.

The optical amplifier shown in FIG. 16  
sets the attenuation quantity of the second variable  
optical attenuator 90 and the monitored value PD1  
25 when the input has the upper limit (or a level other  
than the upper limit). The attenuation quantity of  
the first variable optical attenuator 88 is set to  
the initial value stored in the ROM, for example.

When the change is generated in the input  
30 optical signal, the optical amplifier calculates the  
amount of change of the input optical signal, and  
controls the attenuation quantity of the second  
variable optical attenuator 90 so as to correct the  
amount of change. The amount of change of the input  
35 optical signal per wavelength channel is corrected  
by the control of the attenuation quantity of the  
second variable optical attenuator 90. In addition,

the gain of the entire optical amplifier is controlled constant by the AGC using the monitored values PD3 and PD5, and the attenuation quantity of the first variable optical attenuator 88 is  
5 controlled so as to maintain the EDF gain target value.

In FIG. 18, "X" indicates an input signal power, and " $\alpha$ " indicates an amount of change. Further, "L1" indicates the attenuation quantity of  
10 the first variable optical attenuator 88, "L2" indicates the attenuation quantity of the second variable optical attenuator 90, and "A" indicates the gain of the entire optical amplifier.

FIG. 19 is a system block diagram showing  
15 a fifth embodiment of the optical amplifier according to the present invention. In FIG. 19, those parts which are the same as those corresponding parts in FIG. 11 are designated by the same reference numerals, and a description thereof  
20 will be omitted. The optical amplifier shown in FIG. 19 differs from the optical amplifier shown in FIG. 11 in that the photodetector 230 shown in FIG. 11 is omitted. The optical amplifier shown in FIG. 19 stores the characteristics of the variable optical  
25 attenuator in the form of a table or function, and drives the variable optical attenuator based on a value which is processed by a microcontroller or the like.

The gain Amp\_Gain of the entire optical  
30 amplifier, the EDF gain EDF\_total\_Gain, and the attenuation quantity VOA\_Loss of the variable optical attenuator 198 may be obtained as follows using the monitored values PD1 and PD3. A sum of the monitored value PD1 and the attenuation quantity  
35 of the variable optical attenuator 198 corresponds to the optical power of the input optical signal.

$$\begin{aligned}\text{Amp\_Gain} &= \text{PD3} - (\text{PD1} + \text{VOA\_Loss}) \\ \text{EDF\_total\_Gain} &= \text{Amp\_Gain} + \text{VOA\_Loss}\end{aligned}$$

The gain of the entire optical amplifier  
5 is controlled by driving the laser diodes 212 and  
232 so that the gain of the entire optical amplifier  
calculated from the monitored values PD1 and PD3  
becomes the desired value. Since the structure of  
the AGC circuit 216 is the same as that shown in FIG.  
10 7, illustration and description thereof will be  
omitted.

Similarly to the second embodiment  
described above, the ALC operation calculates the  
change in the input optical signal per wavelength  
15 channel from the monitored value of the input  
optical signal and the output optical signal, and  
drives the variable optical attenuator 198 using the  
calculated value as the target value.

Furthermore, the optical amplifier shown  
20 in FIG. 19 controls the EDF gain constant by using  
the AGC circuit 218 having a structure shown in FIG.  
12. The voltage signals from the photodetectors 214  
and 234 are amplified in the corresponding  
amplifiers 240 and 244 having fixed gains, and  
25 supplied to the corresponding ADCs 246 and 250. The  
ADCs 246 and 250 convert the voltage signals from  
the respective photodetectors 214 and 234 into  
digital signals, and supply the digital signals to  
the microcontroller 252.

30 Similarly to the third embodiment  
described above, the microcontroller 252 can  
calculate the EDF gain by adding the gain of the  
entire optical amplifier and the attenuation  
quantity of the variable optical attenuator 198.  
35 For this reason, by driving the variable optical  
attenuator 198 so that the attenuation quantity of  
the variable optical attenuator 198 becomes the

target value VOA\_Loss, the microcontroller 252 can control the EDF gain constant.

$$\begin{aligned} & \text{(VOA\_Loss Target Value)} = \text{(Gain of Entire} \\ 5 \quad & \text{Optical Amplifier)} - \text{(EDF Gain Target Value)} \end{aligned}$$

The microcontroller 252 calculates the target value of the attenuation quantity of the variable optical attenuator 198, and controls the  
10 variable optical attenuator 198 so that the attenuation quantity thereof becomes the target value. A control signal which is output from the microcontroller 252 so as to control the variable optical attenuator 198 is converted into a voltage  
15 signal by the DAC 254, and is supplied to the driving circuit for the variable optical attenuator 198. This driving circuit includes the amplifier 256, the transistor 258 and the resistor R5.

Next, a description will be given of the  
20 operation of the optical amplifier shown in FIG. 19, by referring to FIG. 20. FIG. 20 is a table showing each monitored values of the optical amplifier and changes in attenuation quantities of the variable optical attenuator 198.

25 The optical amplifier shown in FIG. 19 sets the attenuation quantity of the variable optical attenuator 198 and the monitored value PD1 when the input has the upper limit (or a level other than the upper limit). The attenuation quantity of  
30 the variable optical attenuator 198 is set to the initial value stored in the ROM, for example.

When the change is generated in the input optical signal, the optical amplifier calculates the amount of change of the input optical signal, and  
35 controls the attenuation quantity of the variable optical attenuator 198 so as to correct the amount of change. The amount of change of the input

optical signal per wavelength channel is corrected by the control of the attenuation quantity of the variable optical attenuator 198. In addition, the gain of the entire optical amplifier is controlled  
5 constant by the AGC using the monitored values PD1 and PD3, and the attenuation quantity of the variable optical attenuator 198 is controlled so as to maintain the EDF gain target value.

In FIG. 20, "X" indicates an input signal power, and " $\alpha$ " indicates an amount of change.  
10 Further, "L" indicates the attenuation quantity of the variable optical attenuator 198, and "A" indicates the gain of the entire optical amplifier.

Therefore, according to this embodiment,  
15 the wavelength characteristic of the gain is maintained constant for the entire optical amplifier, by controlling the variable optical attenuator 198. Hence, compared to the conventional case where the wavelength characteristic of the gain is maintained  
20 constant by carrying out the AGC with respect to each of the plurality of optical amplifier units, it is possible to cope with a high-speed AGC because the structure related to the control of the optical amplifier is simplified.

25 In addition, since the structure related to the control of the optical amplifier is simple, it is possible to reduce the number of required parts. As a result, this embodiment of the optical amplifier can greatly reduce the cost of the optical  
30 amplifier due to the reduced number of required parts, and also reduce the mounting surface area due to the reduced number of required parts.

Further, the present invention is not limited to these embodiments, but various variations  
35 and modifications may be made without departing from the scope of the present invention.